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Ciência & Tecnologia dos MATERIAIS

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Ciência & Tecnologia dos Materiais 28 (2016) 47–54

Multilayer nitride coating performance optimized by an artificial neural network approach

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Abstract

One of the most important problems occurred in many industries is due to friction and wear process. Over the years, minimizing friction and controlling wear is one of the difficult tasks for the researchers. Both properties can be minimized by the application of adequate coating technology. Many coating deposition technologies have been employed to limit friction and wear but only few succeeded, those are directly affected by the nature of the material under investigation and process parameters. A suitable coating strategy varying from single layer to multilayer should be applied to the materials whose superficial properties such as low friction, improved wear resistance, and adhesion are the prime interest. Multilayer coatings possess high hardness, ductility and fracture strength compared to single layer coatings. The advantageous properties of these multilayers can be preciously tailored according to specific application. For this purpose Physical Vapour Deposition (PVD) coatings have been developed considerably due to increasing industrial demands. In the present research, friction and wear study of multilayer PVD-nitride coating deposited on tool steel by unbalanced reactive magnetron sputtering technique have been discussed. Later on an Artificial Neural Network approach was used to predict the tribological properties of multilayer nitride films. Bias voltage, total gas flow rate, lap, time, velocity and load were considered as controllable factors. The regression and performance curve analysis is used to assess the optimized outcome of deposited film properties such as friction and wear. The analyzed results shows that experimented and predicted values are in a good agreement.

Keywords: physical vapour deposition; nitride; artificial neural network; friction; wear.

1. Introduction

In a modern world, steel research have been considerably gaining importance due to its impact on day to day life and varying from biological replacements to micro industries to heavy machineries. More noble materials are identified and developed during past years either through alloying one or more than two materials. At a same time their mechanical, physical and chemical properties are triggered through newly developed coating technologies and are handful to strengthened the materials functional properties such as tribological optical, electrical and electronic. Coating tribology is constantly increasing and fulfils the demands of tool steels such as drilling, moulding, blanking etc. in an efficient way by improving their friction and wear properties [1]. Surfaces with nitride coatings on tool steels reflect high lattice energy and strong attraction towards metallic cations. These nitride coatings with addition of tungsten reduce tensile stresses in the coating zone and develop compressive stresses during PVD process. The type of coating like chemical vapour deposition (CVD) [2], physical vapour deposition (PVD) and plasma spray process [3] mainly based on the type of application required and materials chemical-physical properties.

Nowadays, in order to get the desired properties such as mechanical, physical and chemical, PVD coatings

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http://dx.doi.org/10.1016/j.ctmat.2015.10.003

gaining valuable interest varying from monolayer to multilayer. These Multilayer coatings exhibit increased life with fracture resistance, adhesion, Young's modulus and improved wear resistance compared to monolayer analogues. Low friction and wear can be obtained by adding various monolayers in a thin and hard multilayer coating [4,5] with the help of PVD process. These multiple monolayer on the material surface changes the overall surface property and gives lower friction and wear values compared to initial one; which is depends on the relationship between material and corresponding nitride coating [6]. With the combined effect of these advantages it is important to evaluate its tribological properties.

Artificial neural network (ANN) is an appropriate tool to study complex processes and it obtain using only data generated by the model and an automatic training procedure. Recently, ANN have been applied to the complex problem in the field of engineering such as aerospace, manufacturing, electronics, measurement, plasma science and materials and metallurgy [7,8]. The most advantageous thing of this technique is non dependency of concerned material property [9]. ANN approach have been a focus of interest over the last decade and give powerful means for optimization, prediction, system identification, control, classification, and non-linear mappings. ANN had been shown to be a superior design method for non-linear model where the network itself is a non linear [10] system.

To the best of author's knowledge first time ever multilayer PVD tungsten nitride coatings were sputtered on chromium-molybdenum-vanadium tool steel to investigate its tribological properties. In the present research, multilayer tungsten nitride coatings were deposited through PVD-unbalanced reactive magnetron sputtering technique and their tribological performance characteristic were evaluated through Pin on Disk (POD) machine. Furthermore, parameters were optimized by ANN technique to predict the characteristics of experimented material. The approached ANN method is suitable for industrial point of view where we can predict the results for the future event. Sometimes, due to time constraint it is very hard to evaluate step by step properties of the materials, those are under investigation. To overcome from such difficulties ANN is employed to predict system behaviour at given input variables. Artificial Neural Networks have been applied to the problems those are too complex to be found such as regression analysis, prediction outcomes, and pattern recognition which makes it very flexible and powerful tool to solve real world problem with ease.

2. Materials and Methodology

High alloyed chromium-molybdenum-vanadium tool steel of hardness 52HRC with following (C: 0.39wt.%, Cr: 5.2wt.%, Mo: 1.4wt.%, Si: 1.0wt.% and V: 0.9wt.%) composition were employed as a testing substrate. An alumina ball (93% purity, Hardness: 66HRC) were used as a sliding counterpart. Sliding friction and wear test were conducted with pin on disk apparatus under constant load (5N) and fixed sliding speed (9.41cm/s) in which a vertical pin consists of alumina ball of dia 6 mm rotates against a prepared substrate.

Multilayer tungsten/tungsten nitride (W/W_2N) PVD coatings were deposited through commercial magnetron sputter unit. The specimens were mirror polished (1μm diamonds) with surface roughness value of <20nm before deposition and further ultrasonically cleaned in acetone for 5 min and dried it for approximately 20min in a vacuum dryer. The coating deposition parameters are as follows: coating temperature 300°C, the DC substrate bias voltage -75V, gas flow rate 60sccm and partial pressure of 0.093Pa respectively. Total six sub-layers of W/W_2N thin film were deposited on substrate with total coating thickness of 2.70 μm whereas, layer thickness of W/W_2N were 0.3 μm and 0.6μm respectively.

2.1. ANN training, optimization and problem formulations

The artificial neural network (ANN) is a non-linear data modelling, mapping [11] tool that has been found a wide practice in engineering sciences. ANN technique is versatile and used by many researchers for predicting the range of applications such as optical properties [12], tribological properties [13], manufacturing process control [14] and in-flight particle characteristics [3]. The network consists of input layer, hidden layer and an output layer (Fig. 1). It used to model complex relationship between a set of inputs and outputs without any prior assumption. Therefore it is considered as a non-linear statistical data modelling tool. Neuron is the basic unit in the network and they are connected to each other with weight factors [15,16]. Simulation of the values and outputting the final vector is done by feeding the data forward through each layer whereas, network training is performed by calculating the output node error and sending them back through the network to aid in weight